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# Revenue Management vs. Newsvendor Decisions: Does Behavioral Response Mirror Normative Equivalence?

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We study and compare decision-making behavior under the newsvendor and the two-class revenue management models, in an experimental setting. We observe that, under both problems, decision makers deviate significantly from normative benchmarks. Furthermore, revenue management decisions are consistently higher compared to the newsvendor order quantities. In the face of increasing demand variability, revenue managers increase allocations; this behavior is consistent with normative patterns when the ratio of the selling prices of the two customer segments is less than 1/2, but is its exact opposite when this ratio is greater than 1/2. Newsvendors' behavior with respect to changing demand variability, on the other hand, is consistent with normative trends. We also observe that losses due to leftovers weigh more in newsvendor decisions compared to the revenue management model; we argue that overage cost is more salient in the newsvendor problem because it is perceived as a direct loss, and propose this as the driver of the differences in behavior observed under the two problems.

*Key words:* behavioral operations management; revenue management; newsvendor problem
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## 1. Introduction

The newsvendor model, which sets the order quantity of a product with uncertain demand, is the base model for inventory management, and has received significant attention in the behavioral literature in the past decade (see e.g., Bolton and Katok 2008, Schweitzer and Cachon 2000). The two-class revenue management model, on the other hand, where the decision maker allocates a fixed capacity between two customer segments (low- and high-end), is the oldest revenue management model still in use, and captures the essential features of revenue management settings such as finite supply of inventory, price differentiation, a fixed sales horizon, and uncertain demand. Under both problems, the decision maker tries to find the quantity to order/allocate that would minimize instances of unsold units and turned away (high-end) customers (in the revenue management framework, the low-end segment exists solely to compete on capacity that would otherwise remain unsold). At the normative, that is, expected earnings maximizing, decision, the costs of ordering/allocating too many units (overage), and too few units (underage) are matched. In particular, when the problem parameters are set accordingly, these two problems are mathematically equivalent, that is, they yield the same normative decision. However, there are behavioral differences between the two problems. Newsvendors' aim is to maximize profits, whereas in revenue management settings, earnings are stated in terms of revenues, because typically fixed costs are high and variable costs are negligible. The capacity constraint is also missing in the newsvendor problem; the decision maker sets an order quantity, whereas the revenue manager makes an allocation decision between two customer segments.

In this paper, we study and compare decision-making behavior in an experimental setting, under these two base operations management models. Although newsvendor and revenue management decisions have been studied from a behavioral perspective before (see below for a detailed review of the literature), we are not aware of any study that compares decision making under the newsvendor and the two-class revenue management models. Furthermore, the previous behavioral work on revenue management (Bearden et al. 2008, Bendoly , 2011, 2013) focuses on a different problem than the one we consider, where each customer has a different valuation for the product (while we focus on two customer segments) and the firm can accept or reject a bid (unlike our setting, where demand is refused only if there are no remaining units for sale); our results complement their findings on decision making in revenue management settings. Revenue management applications are mostly automated in areas such as transportation and accommodation, where policies are implemented over many instances. In other industries, with a few large events per year, however, such as sports and entertainment events management, or broadcasting, there is room for individual decision making. For example, "tour operator revenue management is largely a manual operation, with analysts trawling through text reports to see what capacity is selling well and what is not, and manually implementing price changes or barring holidays from sale in response to this information" (Jarvis 2002). Since managers responsible from revenue management applications are not necessarily trained in optimization methods, we believe insights about actual revenue management decision-making behavior would prove valuable.

Our results might also provide behavioral research directions about decision making under other, mathematically equivalent but behaviorally distinctive, operations management models. For example, Talluri and van Ryzin (2004) argue allocating capacity and managing prices are mathematically equivalent in the revenue management context, because both limiting supply and increasing prices can achieve reducing sales. Similarly, for a manufacturer, offering quantity discount schedules or a fixed fee plus single price contract are normatively equivalent (Ho and Zhang 2008), but structurally different.

Our experimental studies show subjects' decisions deviate significantly from normative benchmarks under both the newsvendor and the revenue management problems. In fact, average decisions are significantly lower than the normative levels when the ratio of cost to price (or the low-end price to the high-end price) is less than 1/2, and they are significantly higher when this relationship is reversed. This behavior is consistent with the findings in the behavioral newsvendor literature.

Normative theory predicts, under equivalent price, cost and demand parameters, newsvendors and revenue managers would order/allocate the same amount. However, we observe that, under the same set of parameters, our revenue managers consistently allocate more to the high-end segment compared to newsvendor order decisions. Furthermore, from a performance perspective, revenue managers are left with significantly more unsold units compared to newsvendors, while the amount of lost sales experienced under the two problems is similar.

Our experimental design also allows us to study the direction of the change in newsvendor and revenue management decisions with respect to changing demand variability. Demand factors have been acknowledged as the major source of uncertainty in many operations management models (Davis 1993), and have a considerable impact on their results and how operational processes are managed. We observe that newsvendors' behavior is consistent with normative trends; they order more in response to an increase in demand variability when the ratio of cost to price is less that 1/2, and display the opposite behavior when this ratio is greater than 1/2. Revenue managers, on the other hand, consistently allocate more to the high-end segment as its demand gets more variable, regardless of the ratio of prices; this pattern is the opposite of normative behavior when the ratio of low-end to high-end price is greater than 1/2.

As discussed above, although mathematically equivalent, the newsvendor and the revenue management problems differ structurally in terms of their objective (profit vs. revenue maximization). This difference is reflected in the costs of overage and underage incurred under the two models. In particular, when newsvendors order too many units relative to demand, they incur negative earnings (because they have already paid for these units), whereas revenue managers experience neither loss nor gain, since variable costs are negligible. When sales are lost due to ordering/allocating too few units relative to demand, however, both revenue managers and newsvendors experience foregone potential earnings (in the amount of the unit margin). Prior research has shown that the nature of losses incurred might impact decision making (see e.g., Frederick et al. 2009, Ho et al. 2010, and Thaler 1980) in the newsvendor context, which suggests this difference in overage costs might render minimizing instances of unsold units more salient to newsvendors. This would explain the behavioral patterns observed under the two problems; while trying to avoid overage, newsvendors would end up ordering fewer units than revenue managers' allocations to the high-end segment. Indeed, in our study, we observe that losses due to leftovers weigh significantly more in newsvendor orders compared to revenue management decisions. Furthermore, newsvendors change decisions more frequently and in greater amounts in response to overage compared to revenue managers.

*Literature review.* There is a growing body of work in the operations management literature which shows that decision makers do not generally behave as prescribed in analytical models. The seminal paper in this stream is due to Schweitzer and Cachon (2000), who study the newsvendor problem in an experimental setting, and establish the pull-to-center effect, which refers to the decision makers' tendencies to place orders between the normative order quantity and the mean demand. The pull-to-center effect is confirmed by Benzion et al. (2008), Bolton and Katok (2008), and Bostian et al. (2008). Other experimental works on the newsvendor problem have extended Schweitzer and Cachon's (2000) framework to study the impact of feedback frequency (Lurie and Swaminathan 2009), group decision making (Gavirneni and Xia 2009), impact of information (Gavirneni and Isen 2010), framing (Schultz et al. 2007), the relationship between cognitive reflection and newsvendor decisions (Moritz et al. 2013), loss aversion and source of income (Becker-Peth et al. 2013), random errors in ordering (Kremer et al. 2010), reference dependence (Ho et al. 2010), and overconfidence (Ren and Croson 2013). Although most of the laboratory analysis of the newsvendor problem has been done with students as subjects, Bolton et al. (2012) show that experienced managers' behavior is very similar.

Bearden et al. (2008) provide an experimental study of decision making in the revenue management context, and consider different decision-making heuristics that may be employed by the subjects. Bendoly (2011) uses a set up similar to Bearden et al.'s (2008) to investigate the influence of arousal and stress, and forms of feedback (2013) on revenue management decisions.

Additional work in the behavioral operations management literature includes studies on the supply chain model (Katok et al. 2008, Loch and Wu 2008a), particularly the causes of the bullwhip effect, that is, the large variation in orders, particularly those placed upstream, as a result of small changes in demand (see Croson and Donohue 2002 for a review, also Bloomfield et al. 2007, Croson , and Donohue 2003, 2006, Katok and Wu 2009). For detailed reviews of the behavioral operations management literature, the reader is referred to Bendoly et al. (2006), Gino and Pisano (2008), Loch and Wu (2008b), and Bendoly et al. (2010).

*Structure.* The rest of the paper is organized as follows. The next section outlines the normative newsvendor and revenue management problems, the details of our experimental design, and laboratory implementation. Section 3 presents our experimental results. Section 4 provides a summary and discussion of our findings. Section 5 concludes the paper.

## 2. Analytical Background and Experimental Design

### 2.1. Analytical Background

In the newsvendor problem (NV), a decision maker facing uncertain demand $\mathbf{D}$ has to decide how many units to order of a given product at cost per unit $c$, to be sold at price $p$. In the standard two-class revenue management model (RM), on the other hand, the decision maker determines the allocation of a fixed quantity of a flexible resource between two customer segments (class 1 and class 2) with sequential prices ($p_1$ and $p_2$, with $p_1 > p_2$ without loss of generality), and uncertain demands $\mathbf{D}_1$ and $\mathbf{D}_2$. In this setting, class 2 demand arrives before class 1 demand, and the decision maker sets the protection level, that is, the number of units reserved for class 1; the remaining units are available for sale to class 2. The objective is profit maximization in the newsvendor model, whereas in revenue management settings, earnings are stated in terms of revenues. We denote the decision under both problems (i.e., *order quantity* in newsvendor, and *protection level* in revenue management) by $x$; both are set before the realization of demand(s).

The normative, that is, expected profit/revenue maximizing, decision for both models solves

$$x^* = F^{-1}\left(\frac{c_U}{c_U + c_O}\right),$$

where $c_U$ is the cost of having too few units relative to demand (underage), $c_O$ denotes the cost of having too many units relative to demand (overage), and $F^{-1}$ is the inverse of the cumulative distribution function for the (class 1) demand (as noted previously, in the revenue management framework, class 2 exists solely to compete on capacity that would otherwise remain unsold; hence the normative allocation is not a function of its demand).

Under the newsvendor problem, the cost of being left with unsold units is $c_O = c$, since the decision maker has already paid for these units, whereas the cost of turning away customers is the profit per unit, $c_U = p - c$. In the revenue management setting, if there is overage, the decision maker is left with unused capacity that cannot be offered to class 2 customers again, because of the sequence of demand arrivals; hence, the cost of having too many units relative to demand is $c_O = p_2$. If actual class 1 demand exceeds the protection level, on the other hand, units that could have been sold to class 1 are sold to class 2 customers earlier in the sales horizon at a lower price, leading to a cost of underage of $c_U = p_1 - p_2$. Remark that, when $\mathbf{D}$ and $\mathbf{D}_1$ have the same probability distribution, and $p = p_1$ and $c = p_2$, the revenue management and the newsvendor problems are mathematically equivalent, that is, they yield the same normative decision $x^* = F^{-1}\left(\frac{p-c}{p}\right) = F^{-1}\left(\frac{p_1 - p_2}{p_1}\right)$. For more on the analytical solution to the newsvendor and the two-class revenue management problems, the reader is referred to Porteus (2002), respectively Littlewood (1972).

### 2.2. Experimental Design

We employed a 2 × 2 design in our experiments, resulting in four distinct conditions. The first factor distinguishing the conditions was the problem the subjects were given (NV, RM), and the second was the price and cost levels (high-cost, low-cost; discussed in detail below).

The subjects assigned to the newsvendor conditions were asked to determine the order quantity for a product with a predetermined unit cost and selling price, to satisfy an uncertain demand with a given distribution. Those who were assigned to the revenue management conditions, on the other hand, were asked to allocate 120 airline seats between two customer segments with sequential price levels and uncertain demands (this setting was chosen because the airline industry is the major adopter of revenue management practices). All subjects were required to complete 40 experimental rounds.

There were two cost conditions in our studies. Under the *low-cost condition*, the prices for the customer segments were set at $p_1 = 120$ and $p_1 = 30$ for the revenue management problem, and the selling price was given as $p = 120$ and the unit cost as $c = 30$ for the newsvendor problem, to ensure their normative equivalence. Under the *high-cost condition*, on the other hand, we had $p = p_1 = 120$ and $c = p_2 = 90$. Remark that, under the high-cost condition, overage is more detrimental to earnings (because of the higher cost/class 2 price); underage hurts earnings more under the low-cost condition (because the unit margin $p{-}c = p_1 - p_2$ is higher).

The uncertain demands were distributed *Uniform* under both models. We manipulated the demand distributions to investigate the impact of changing demand variability on subject behavior (in the revenue management conditions, only class 1 demand was manipulated; class 2 demand remained constant throughout the experimental rounds, and was distributed *Uniform*(50,170)). In particular, demand parameters were changed in a manner that preserved the mean, while changing the variance every 10 rounds. To check for order effects, some subjects were given parameters that corresponded to increasing demand variability, while the rest faced decreasing demand variability (order effects refer to the possibility that subjects' experiences in an experiment might bias their decisions in following experiments; see for example, Camerer 2003). The parameters of the specific demand distributions used, corresponding means, variances, and normative decisions are given in Table 1. Recall from above that, for both problems, the normative decision is given by $x^* = F^{-1}\left(\frac{c_U}{c_U + c_O}\right)$. In particular, when demand is distributed *Uniform* $(a,b)$, $x^* = b - \frac{c}{p}(b-a) = b - \frac{p_2}{p_1}(b-a)$. Note that, the normative order quantity/protection level decreases as the demand variability increases in the high-cost condition; in order to avoid ending up with unsold units, which hurts earnings more, and which now has a higher probability because of the shift of the probability mass from the center to the tails, the decision maker orders/sets aside fewer units. The opposite behavior maximizes expected profits/revenues in the low-cost condition; decision maker increases orders/protection levels to avoid lost sales, as underage is more detrimental to earnings in this case.

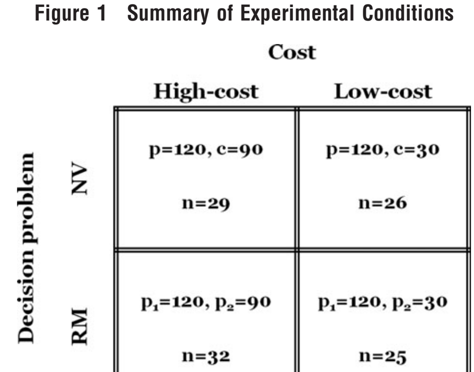
**Table 1 Demand Treatments**

| | | | Normative decision | |
|---|---|---|---|---|
| Demand | Mean | Variance | Low-cost | High-cost |
| *Uniform*(0,80) | 40 | 533.33 | 60 | 20 |
| *Uniform*(10,70) | 40 | 300 | 55 | 25 |
| *Uniform*(20,60) | 40 | 133.33 | 50 | 30 |
| *Uniform*(30,50) | 40 | 33.33 | 45 | 35 |

A total of 112 subjects participated in our study. No subject participated in more than one condition. A summary of our experimental conditions and the number of subjects in each condition are given in Figure 1.

*Laboratory implementation.* All experimental sessions followed the same protocol. When the subjects arrived at the experimental laboratory, they were given instructions that described the newsvendor or the airline revenue management problem (according to the condition they were assigned to), their objective, the concepts of overage and underage, and the experimental protocol. After all the subjects finished reading the instructions on their own, the experimenter read them aloud, using PowerPoint slides to illustrate concepts and examples, and answered questions. At the end of this training period, a short test was administered to the subjects to ensure they understood the instructions. Only the participants who completed the test successfully began the experimental rounds.

**Figure 1 Summary of Experimental Conditions**



The experiments were conducted with specifically programmed software based on the Visual Basic for Applications (VBA) platform. At the beginning of each round, subjects were provided with the demand distribution, price, cost, and capacity information for that round, based on the experimental condition they were assigned to. After making their decision, they learned the actual demand(s) for that round, as well as realized profits/revenues, the number of unsold units, and the number of turned away customers. Demand realizations were determined prior to the experiment, and were the same for every subject. An information message was displayed on the screen when there was a change in the problem parameters.

Subjects were briefed and dismissed after they completed 40 experimental rounds; they were not informed of the total number of rounds prior to the experiment. None of the subjects received information about others' performance and subjects were not allowed to communicate with each other during the experiment. Each session lasted approximately 90 minutes, including the training period and the pilot rounds.

## 3. Results

Table 2 provides descriptive statistics for our subjects' decisions, including the average and normative decisions, and standard deviation between subjects. Figures 2 and 3 provide a visual summary (histograms of our subjects' decisions are provided in Figures A1–A8 in the Appendix).

For the majority of our analyses, we used the Wilcoxon test (Siegel 1956) for the comparisons. We checked our data for any order effects, that is, we compared the average decisions of subjects who faced demand treatments in the order of increasing variability and those who faced the opposite demand sequence under all experimental conditions, and observed no significant differences ($p > 0.15$ for all comparisons).

When we compared actual average decisions with the normative benchmarks given in Table 2, we observed significant differences under all experimental conditions and demand treatments considered ($p < 0.0001$ for all comparisons). In fact, at the individual level, the number of times our subjects chose the normative decision accounted for 5.79% of all revenue management decisions, and 8.86% of all newsvendor decisions. Further Wilcoxon tests revealed that, under the low-cost condition, the average decisions were significantly lower than the corresponding normative levels under all demand treatments, while under the high-cost condition, they were significantly higher ($p < 0.0001$ for all comparisons).

### 3.1. Comparison of Decisions under NV and RM

A visual analysis of Figures 2 and 3 reveal that our revenue managers' average decisions were consistently higher compared to our newsvendors. In particular, pairwise Wilcoxon tests revealed that, in the low-cost condition, our revenue managers' average

**Table 2 Descriptive Statistics**

| | NV | | RM | | |
|---|---|---|---|---|---|
| Demand | Average decision | Standard deviation (between subjects) | Average decision | Standard deviation (between subjects) | Normative decision |
| Low-cost ($p = p_1 = 120, c = p_2 = 30$) | | | | | |
| *Uniform*(0,80) | 41.41 | 7.21 | 49.06 | 7.03 | 60 |
| *Uniform*(10,70) | 40.94 | 6.12 | 44.24 | 5.61 | 55 |
| *Uniform*(20,60) | 40.13 | 4.86 | 41.07 | 3.82 | 50 |
| *Uniform*(30,50) | 39.40 | 1.71 | 39.96 | 2.67 | 45 |
| High-cost ($p = p_1 = 120, c = p_2 = 90$) | | | | | |
| *Uniform*(0,80) | 33.42 | 8.60 | 43.15 | 7.97 | 20 |
| *Uniform*(10,70) | 35.83 | 6.16 | 39.99 | 6.09 | 25 |
| *Uniform*(20,60) | 35.85 | 4.95 | 38.56 | 3.51 | 30 |
| *Uniform*(30,50) | 38.11 | 2.67 | 38.46 | 2.35 | 35 |

**Figure 2 Subjects' Average Decisions: Low-Cost Condition**

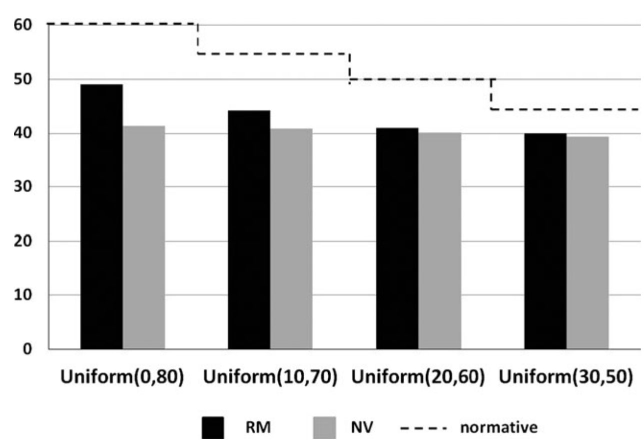
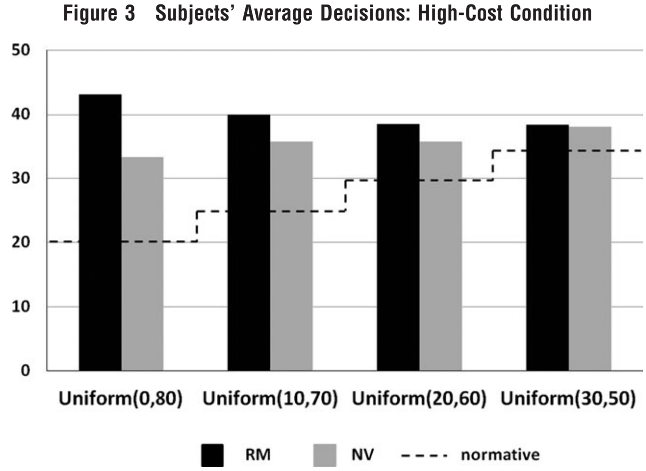



**Figure 3 Subjects' Average Decisions: High-Cost Condition**



allocation decisions were significantly higher compared to the average order quantity under NV when demand was distributed *Uniform*(0,80) and *Uniform* (10,70) ($p < 0.0001$ and $p = 0.053$, respectively), whereas the difference between average revenue management and newsvendor decisions was not significant when demand was distributed *Uniform*(20,60) and *Uniform*(30,50) ($p > 0.5$). The same pattern was observed in the high-cost condition; the difference between the average newsvendor orders and revenue management allocations was significant when demand was distributed *Uniform*(0,80) ($p < 0.0001$) and *Uniform*(10,70) ($p = 0.015$), whereas average protection levels were not significantly higher when demand was distributed *Uniform*(20,60) and *Uniform* (30,50) ($p = 0.092$ and $p = 0.931$, respectively).

The tendency of revenue managers to set higher decisions compared to newsvendors could also be observed at the individual level (see Figures A1–A8 in the Appendix). For example, from Figure A1, in the low-cost condition, when demand was distributed *Uniform*(0,80), the majority of newsvendor decisions (71.92%) were between the normative quantity ($x^* = 60$) and the mean demand (40); the percentage of revenue management decisions which fell in this range was 57.60%. In fact, allocation decisions under RM were clustered around a higher range; 68.40% of all revenue management decisions were between 50 and 70 in this case. Similarly, under the same demand treatment in the high-cost condition (Figure A5), 79.06% of our revenue managers' allocation decisions were in the range [30,60], whereas newsvendor order quantities tended to fall between 20 and 50 (77.59% of all decisions). Similar patterns were observed under the other demand treatments.

Revenue managers and newsvendors also displayed different behavioral patterns with respect to changes in demand variability. Figure 4 provides a visual summary. In particular, the change in the direction of average revenue management and newsvendor decisions were consistent with normative predictions in the low-cost condition; they increased in demand variability. In the high-cost condition, our revenue managers' average allocations again increased as demand variability increased, while average newsvendor order decisions decreased. As outlined above, normative theory prescribes lower decisions in response to higher demand variability in this case. However, differences between average decisions across demand treatments were not uniformly significant (individual $p$-values are given in Table 3).

We conclude this subsection with the results from a dummy-variable regression analysis that summarizes the findings presented above, and provides an evaluation of our subjects' decisions from a performance perspective.

**Figure 4 Normative vs. Subjects' Average Decisions with Respect to Demand Variability**

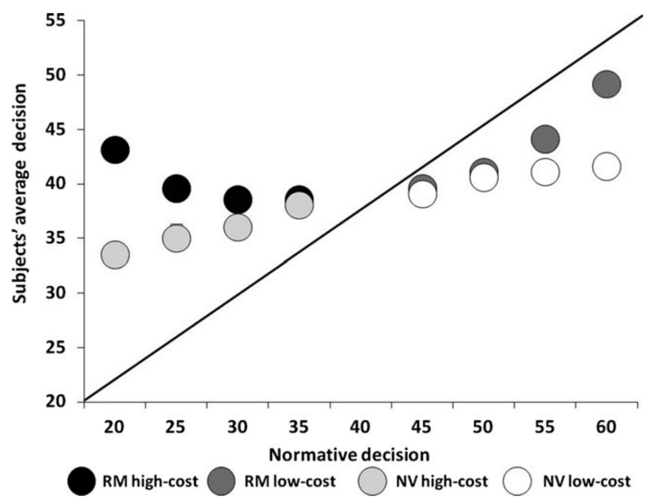



**Table 3 p-Values for Comparisons with Respect to Demand Variability**

| | Demand | Uniform (0,80) | Uniform (10,70) | Uniform (20,60) | Uniform (30,50) |
|---|---|---|---|---|---|
| NV | High-cost | $33.42<_{p\,=\,0.018}$ | $35.83<_{p\,=\,0.482}$ | $35.85<_{p\,=\,0.007}$ | 38.11 |
| | Low-cost | $41.41>_{p\,=\,0.483}$ | $40.94>_{p\,=\,0.137}$ | $40.13>_{p\,=\,0.194}$ | 39.40 |
| RM | High-cost | $43.15>_{p\,=\,0.004}$ | $39.99>_{p\,=\,0.103}$ | $38.56>_{p\,=\,0.526}$ | 38.46 |
| | Low-cost | $49.06>_{p\,=\,0.001}$ | $44.24>_{p\,=\,0.001}$ | $41.07>_{p\,=\,0.031}$ | 39.96 |

In particular, we regressed the deviations of the subjects' decisions from normative benchmarks on dummy variables representing the problem (NV or RM) and the demand treatments, for both low- and high-cost conditions. In all the regressions, we took the revenue management problem and the demand treatment *Uniform*(0,80) as the baseline cases. Our regression equation under the low-cost condition was thus $(x^* - x_{ij}) = \alpha + \delta P + \Sigma\beta_k X_k + \varepsilon$, and under the high-cost condition it was $(x_{ij} - x^*) = \alpha + \delta P + \Sigma\beta_k X_k + \varepsilon$, where $x_{ij}$ denotes the decision of the $i$th subject in round $j$, and $x^*$ is the corresponding normative decision, with the coefficient of the variable $P$ representing the effect of the problem switching from RM to NV, and the coefficients of $X_1$, $X_2$ and $X_3$ indicating the effects of demand treatment changing from the base demand level of *Uniform*(0,80) to *Uniform*(10,70), *Uniform*(20,60) and *Uniform*(30,50), respectively. Table 4 presents the results from this analysis, which show that, in the low-cost condition, decisions were closer to the normative levels under the revenue management problem compared to the newsvendor problem, while this relationship was reversed in the high-cost condition. Furthermore, the distance between subjects' decisions and the normative benchmarks decreased as demand variability got lower, under both cost conditions.

**Table 4 Regression Analysis: Deviations from Normative Benchmarks**

| | Deviations from normative decisions | |
|---|---|---|
| | Low-cost | High-cost |
| Problem: NV vs. RM | 3.1** | −4.2** |
| Demand treatment | | |
| *Uniform*(10,70) vs. *Uniform*(0,80) | −2.4** | −5.5** |
| *Uniform*(20,60) vs. *Uniform*(0,80) | −5.4** | −11.3** |
| *Uniform*(30,50) vs. *Uniform*(0,80) | −9.5** | −15.2** |
| Constant | 13.3** | 20.5** |
| $N$ | 2040 | 2440 |
| $R^2$ | 11% | 23.8% |

$^{**}p < 0.001$.

### 3.2. Comparison of Overage and Underage under NV and RM

We also compared the amount of overage and underage experienced under the newsvendor and the revenue management models. We conducted a dummy-variable regression analysis, similar to the one presented in the section above, to study the impact of the problem the subjects were assigned to (NV or RM) on the amount of lost sales and unsold units. Specifically, our regression equation for the amount of overage was $(x_{ij} - d_j) = \alpha + \delta P + \Sigma\beta_k X_k + \varepsilon$, and similarly, for the amount of underage, $(d_j - x_{ij}) = \alpha + \delta P + \Sigma\beta_k X_k + \varepsilon$, where $x_{ij}$ denotes the decision of the $i$th subject in round $j$, and $d_j$ is the actual demand realization in round $j$, with the coefficient of the variable $P$ representing the effect of the problem switching from RM to NV on the amount of overage/underage, and the coefficients of $X_1$, $X_2$ and $X_3$ indicating the effects of demand treatment changing from the base demand level of *Uniform*(0,80) to *Uniform*(10,70), *Uniform*(20,60), and *Uniform*(30,50), respectively. Results are presented in Table 5.

We found a significant effect of the problem on the amount of overage experienced under both low- and high-cost conditions. Specifically, the number of unsold units decreased significantly when the problem switched from RM to NV. When we considered the amount of underage, we observed that, under the low-cost condition, the problem did not have a significant effect. Under the high-cost condition, on the other hand, there was a significant increase in the amount of lost sales under the newsvendor problem. It should also be noted that, in terms of the level of demand uncertainty, our regression analysis designated a clear pattern; the amounts of overage and underage reduced significantly as the demand variability decreased, which might be attributed to the set of available decision alternatives being smaller under demand treatments with lower variance.

**Table 5 Regression Analysis: Amount of Overage and Underage**

| | Overage | | Underage | |
|---|---|---|---|---|
| | Low-cost | High-cost | Low-cost | High-cost |
| Problem: NV vs. RM | −1.8* | −1.7* | 0.3 | 2.5** |
| Demand treatment | | | | |
| *Uniform*(10,70) vs. *Uniform*(0,80) | −12.4** | −11.6** | −4.4** | −5.4** |
| *Uniform*(20,60) vs. *Uniform*(0,80) | −15.3** | −12.6** | −8.7** | −9.76** |
| *Uniform*(30,50) vs. *Uniform*(0,80) | −22.8** | −20.0** | −13.9** | −15.6** |
| Constant | 30.0** | 26.2** | 20.7** | 21.9** |
| $N$ | 1138 | 1176 | 823 | 1158 |
| $R^2$ | 32.9% | 29.8% | 22.1% | 22.7% |

$^{*}p < 0.02$, $^{**}p < 0.001$.

We also calculated the average number of unsold units and turned away customers under the two problems. In the low-cost condition, newsvendors were left with, on average, 8.68 unsold units, compared to 10.75 under the revenue management problem ($p = 0.002$); the corresponding figures were 6.29 and 8.30, respectively, in the high-cost condition ($p = 0.001$). The average amount of lost sales, on the other hand, was 6.11 under NV and 5.08 under RM in the low-cost condition ($p = 0.073$). Under the high-cost condition, newsvendors turned away, on average, 8.38 customers; the corresponding figure was 6.16 for revenue managers ($p = 0.002$) (the average number of unsold units and turned away customers under NV and RM at the demand treatment level is provided in Table A1 in the Appendix).

### 3.3. The Impact of Cost of Overage

As discussed in the Introduction, the difference in behavioral patterns observed under the newsvendor and the revenue management problems, detailed above, might be explained by overage being more salient to newsvendors (as newsvendors incur negative earnings when they have unsold units, whereas revenue managers experience neither loss nor gain).

To pursue this line of investigation, we calculated the *loss parameter* , proposed for the newsvendor problem by Becker-Peth et al. (2013), for each subject. The loss parameter, denoted by $\beta$, measures the weight given to losses due to unsold units in decisions, and can be found by solving $x = F^{-1}(c_U/c_U + \beta c_O)$, where, recall, $F^{-1}$ denotes the inverse of the cumulative distribution function for demand, $c_O$ the cost of overage, $c_U$ the cost of underage, and $x$ a given subject's decision. If overage is more salient to newsvendors, we would expect them to attach a higher weight to losses due to leftover units in their decisions, compared to revenue managers. Indeed, this was the case in our study. The average loss parameter under the newsvendor problem was 5.2 under the low-cost condition; the average weight given to losses due to leftovers under the revenue management problem was significantly lower, 3.92, in the same cost condition

**Table 6 Average Weight of Losses from Overage**

| | Low-cost | | High-cost | |
|---|---|---|---|---|
| Demand | NV | RM | NV | RM |
| *Uniform*(0,80) | 5.02 | 3.02 | 0.99 | 0.40 |
| *Uniform*(10,70) | 4.71 | 3.94 | 0.79 | 0.59 |
| *Uniform*(20,60) | 5.93 | 3.90 | 1.05 | 0.57 |
| *Uniform*(30,50) | 5.14 | 4.81 | 0.84 | 0.63 |

($p$ = 0.03). Under the high-cost condition, the corresponding figures were 0.95 under NV and 0.55 under RM ($p < 0.001$). The average loss parameters at the demand treatment level are provided in Table 6.

Furthermore, our newsvendors showed a stronger tendency to avoid instances of overage compared to revenue managers. Specifically, when we analyzed how our subjects adjusted decisions with respect to the outcome of the previous round, we observed that, newsvendors decreased decisions 81.94% of the time in the next round when they ordered more than demand in the previous round, under the high-cost condition, and 84.77% of the time under the low-cost condition; the corresponding percentages were 56.45% and 81.25%, respectively, for revenue managers. Furthermore, under the low-cost condition, in 21.44% of revenue management decisions, our subjects did nothing when they allocated more than its demand to the high-end class in the previous round; the corresponding percentage for newsvendors was much lower (5.77%). In the high-cost condition, the percentage of repeat choice for revenue managers in response to overage was again higher compared to newsvendors (8.07% vs. 4.98%), but lower than the corresponding percentages in the low-cost condition; this might be attributed to unsold units being more detrimental to earnings in this case. We also calculated the average amount of change in decisions with respect to the previous round; compared to revenue managers, newsvendors decreased orders in greater magnitudes when they experienced leftovers in the previous round under both cost conditions (8.71 units in NV vs. 6.21 units in RM under the high-cost condition, $p$ = 0.019; the corresponding figures were 7.84 and 7.22 units, respectively, under the low-cost condition, $p$ = 0.522).

# 4. Summary of the Results and Discussion

In this study, we studied how structural differences between two normatively equivalent operations management models impact actual decision-making behavior. Specifically, we compared newsvendor orders with allocation decisions under the two-class revenue management framework in a controlled laboratory setting.

We observed that, under both problems, our subjects' decisions deviated significantly from normative benchmarks. In particular, when the ratio of cost to price (or low-end price to high-end price) was less than 1/2, our subjects ordered/allocated significantly fewer units compared to the normative benchmark. When this ratio was reversed, their decisions were significantly higher than the normative level. This result was consistent with the findings regarding the newsvendor problem in the behavioral operations management literature (e.g., Bolton and Katok 2008, Bostian et al. 2008, Schweitzer and Cachon 2000).

Revenue management allocation decisions were consistently higher than the newsvendor orders in our study, under equivalent price, cost, and demand parameters, despite normative theory predicting subjects would order/allocate the same amount. It should be noted, however, that this difference was not significant when demand variability was low, possibly because the set of alternatives available to decision makers was smaller under these treatments (since variability is a measure of how spread out or closely clustered values are).

Revenue managers' and newsvendors' behavioral patterns also differed in terms of how they adjusted decisions with respect to changes in demand variability. Specifically, when the ratio of cost to price was less than 1/2, newsvendors increased orders as demand became more variable. When this ratio was reversed, they decreased orders as variability increased. This behavior was consistent with normative predictions. Revenue managers, on the other hand, increased protection levels in the face of increasing demand variability, regardless of the ratio of prices.

We also observed that, revenue managers consistently experienced more overage compared to newsvendors. The amount of lost sales, on the other hand, was similar under the two problems when the ratio of cost to price (or low-end price to high-end price) was less than 1/2. When this ratio was reversed, that is, when leftovers hurt earnings more, however, newsvendors' decisions led to significantly higher amounts of underage compared to revenue managers.

Further analysis on the decision-making behavior under the two problems revealed losses from overage weighed consistently more in newsvendor orders compared to revenue management decisions. We argue that this is due to the nature of overage cost under the two problems: newsvendors incur negative earnings, because they have already paid for the units than remain unsold, whereas revenue managers experience neither loss nor gain. We also observed that, when newsvendors ordered too many units relative to demand in the previous round, they decreased decisions more frequently, and in greater magnitudes, compared to revenue managers.

We posit that the driver of the behavioral patterns observed in our study is the cost of excess inventory being more salient in the newsvendor problem. Because newsvendors are more averse to losses due to leftovers, they try to avoid overage more, and end up with order levels consistently lower than revenue management allocation decisions. Consequently, they are left with fewer unsold units; in fact, when leftovers hurt earnings more, while trying to avoid overage, newsvendors fall short of demand consistently more compared to revenue managers. Furthermore, when there is an increase in the variability of demand, newsvendors focus on the shift of probability mass from the center to the lower tail when the ratio of cost to price is greater than 1/2, that is, when overage hurts earnings more, and decrease orders as variability increases. Revenue managers, on the other hand, focus on the shift of probability mass to the upper tail regardless of the ratio of prices, because losses due to unsold units are less salient to them, and always increase allocations to the high-end segment in the face of increasing demand variability.

*Relation to literature.* As discussed above, in our experiments, under both the newsvendor and the revenue management problems, we observed decision makers ordering/allocating too few units compared to the normative levels when the ratio of cost to price (or low-end price to high-end price) was less than 1/2, and too many units compared to normative benchmarks when this ratio was reversed. Ren and Croson (2013) suggest this behavior can be caused by *overconfidence*, in particular *overprecision*. Overprecision refers to the belief that own estimates are more accurate than they actually are (Moore and Healy 2008), and can lead to the underestimation of the variance of the demand distribution. Although we did not measure overconfidence levels of our decision makers, based on Ren and Croson's (2013) results, it can be argued that they were overprecise. However, we cannot propose overprecision as an explanation for the differences in behavior observed under the two problems. In our study, revenue management decisions were consistently higher than newsvendor orders. This pattern, alongside the definition of overprecision, would suggest that revenue managers were more overprecise compared to newsvendors when the ratio of cost to price (or low-end price to high-end price) was greater than 1/2, and newsvendors were more overprecise when this ratio was reversed. However, the newsvendor and revenue management models do not differ behaviorally in a manner that would suggest the relationship between the overconfidence levels of decision makers under the two problems would be reversed from one cost condition to the other.

Ho et al. (2010) develop a behavioral model for newsvendor decisions based on *reference dependence* (Kahneman and Tversky 1979, Thaler 1985). They propose that preferences in the newsvendor context are composed of (i) an intrinsic utility associated with final profits, and (ii) a change utility defined with respect to a reference point. In this study, we argue that losses from overage weigh more in newsvendor decisions compared to revenue managers, because newsvendors incur a direct loss when they have leftover units, whereas revenue managers experience neither gain nor loss. An equivalent argument would be the reference point for decision makers under both problems being no profits/revenues (i.e., their earnings position before they make their decisions). If this is the case, when they have leftovers, newsvendors would incur a psychological cost (because they deviate from the reference point), whereas revenue managers would not; this would lead the newsvendors to set lower order quantities compared to revenue managers' allocation decisions.

Becker-Peth et al. (2013) propose a behavioral model based on *prospect theory* and *mental accounting* to explain newsvendor order decisions. Their model accounts for the source of income (from sales to customers or returns to the supplier), and distinguishes between the upside (getting rid of underage) and downside (getting rid of overage) potentials of newsvendor orders. In our setting, both the newsvendor and revenue management incomes come from sales to customers; hence, the source of income cannot provide an explanation for the different decision patterns observed under the two problems. They also propose a loss parameter to formalize the aversion of decision makers to losses from leftovers, which we use to show that the cost of overage weighs more in newsvendor decisions compared to revenue managers, as discussed above.

Finally, it should be noted that, in the newsvendor setting, the impact of changing demand variability has been studied by Lurie and Swaminathan (2009) from a behavioral perspective. Specifically, they provide their subjects with high- and low-variance demand distributions (*Uniform*(1,1000) and *Uniform* (450,500), respectively), and find that, when the ratio of cost to selling price is less than 1/2, order quantities are lower under the low-variance condition compared to the high-variance condition. This result is consistent with our findings. However, they do not study order behavior when the ratio of cost to selling price is greater than 1/2, or under other degrees of demand variability, and do not provide an explanation of the behavioral patterns observed.

## 5. Conclusion

Our results suggest decision makers do not perceive and process the newsvendor and the two-class revenue management models as identical problems, despite their normative equivalence. As mentioned in the Introduction, our results might yield insights about decision making in other mathematically equivalent, but structurally different, operations management models, such as allocating capacity vs. managing prices, or setting the protection level vs. the booking limit (i.e., the number of units available to the low-end segment) in the revenue management context. Clearly, further behavioral studies would be needed to make specific conjectures.

The analysis presented in this study identifies the perceived losses due to leftovers as the main driver of the behavioral patterns observed under the revenue management and the newsvendor problems. Ho et al. (2010) show, biases in newsvendor decisions that are driven by losses from overage and underage might be reduced by making instances of unsold units and lost sales more salient to subjects during the experiment. It might be interesting to extend this research in their spirit, and study whether the relationship between newsvendor and revenue management decisions would be preserved if losses due to unsold units are made more salient to revenue managers.

In the revenue management framework, the low-end segment exists to compete on capacity that would otherwise remain unsold. However, our findings show that decision makers are not able to reap the full benefits of a revenue management system; they allocate more units to the high-end segment (compared to decision makers assigned to a mathematically equivalent problem), and are left with unsold units, which could have been sold to the low-end customers earlier in the sales horizon. Our results also suggest in revenue management applications where the price difference between customer segments is low, such as a restaurant chain which offers discounts to loyalty card owners, decision makers might be inclined to reserve fewer units for the low-end customers in times of high demand variability, while the opposite behavior would be more beneficial to earnings. Clearly, training and incentive mechanisms are required to make managers aware of the biases identified in this study.

# Appendix

**Figure A1 Histogram of Subjects' Decisions: Low-Cost Condition, *Uniform*(0,80)**

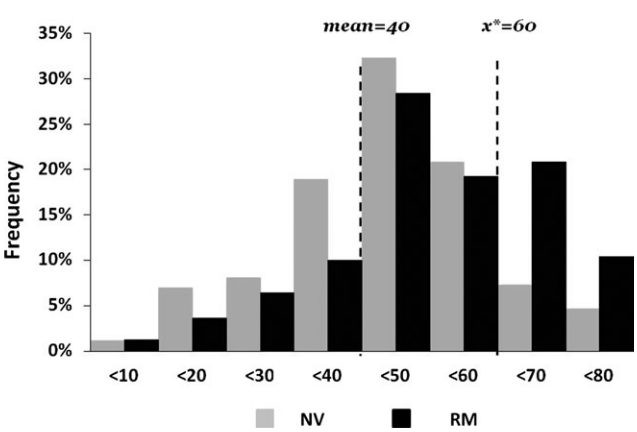



**Table A1 Average Magnitude of Overage and Underage**

| | Overage | | Underage | |
|---|---|---|---|---|
| Demand | NV | RM | NV | RM |
| *Low-cost* ($p = p_1 = 120$, $c = p_2 = 30$) | | | | |
| *Uniform*(0,80) | 16.46 | 22.03 | 8.15 | 6.08 |
| *Uniform*(10,70) | 7.95 | 9.63 | 8.21 | 6.59 |
| *Uniform*(20,60) | 7.55 | 8.07 | 5.11 | 4.70 |
| *Uniform*(30,50) | 2.76 | 3.30 | 2.96 | 2.94 |
| *High-cost* ($p = p_1 = 120$, $c = p_2 = 90$) | | | | |
| *Uniform*(0,80) | 11.79 | 17.45 | 11.47 | 7.40 |
| *Uniform*(10,70) | 5.50 | 6.75 | 10.86 | 7.95 |
| *Uniform*(20,60) | 5.71 | 6.66 | 7.55 | 5.80 |
| *Uniform*(30,50) | 2.15 | 2.33 | 3.64 | 3.47 |

**Figure A2 Histogram of Subjects' Decisions: Low-Cost Condition, *Uniform*(10,70)**

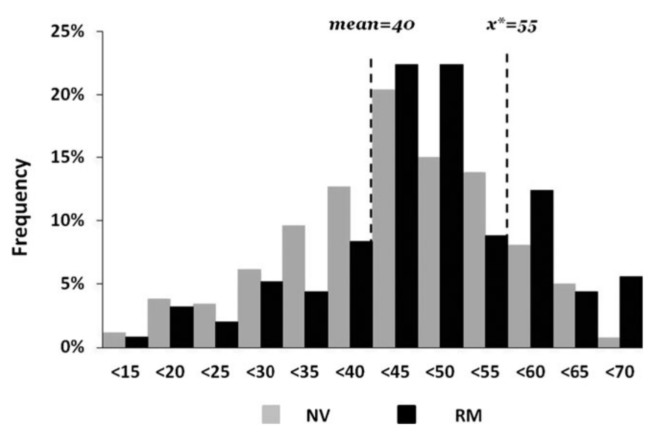



**Figure A3 Histogram of Subjects' Decisions: Low-Cost Condition, *Uniform*(20,60)**

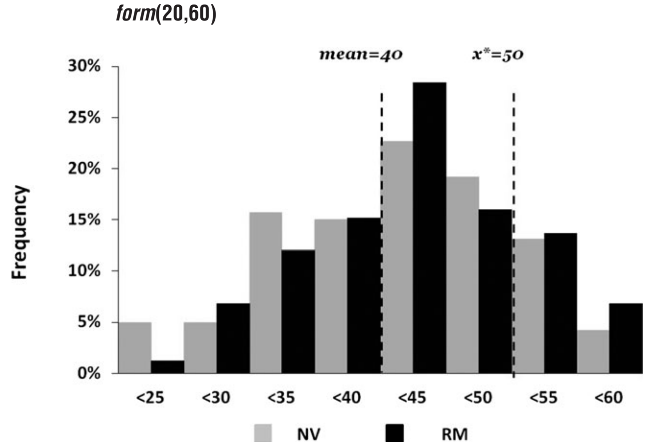


**Figure A4** Histogram of Subjects' Decisions: Low-Cost Condition, *Uniform*(30,50)

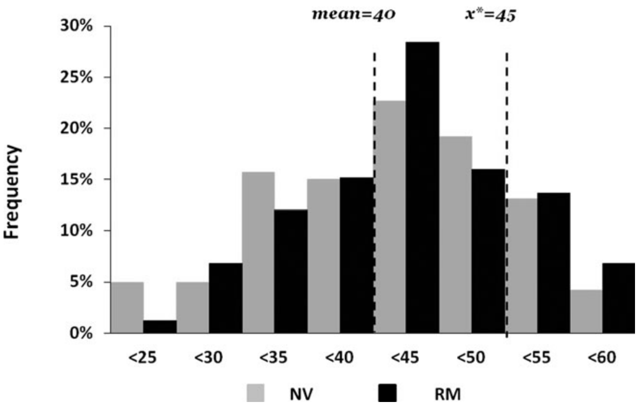



**Figure A5** Histogram of Subjects' Decisions: High-Cost Condition, *Uniform*(0,80)

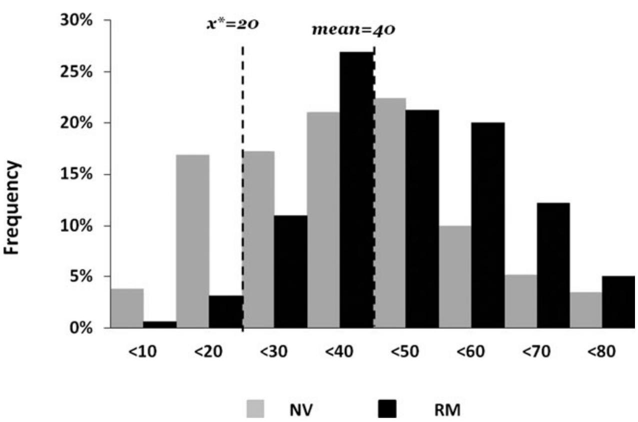



**Figure A6** Histogram of Subjects' Decisions: High-Cost Condition, *Uniform*(10,70)

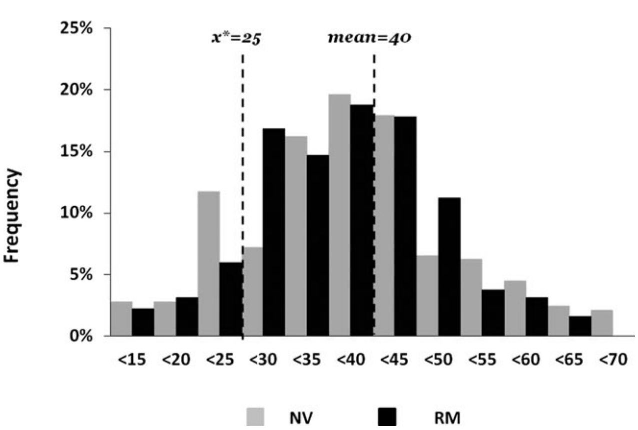



**Figure A7** Histogram of Subjects' Decisions: High-Cost Condition, *Uniform*(20,60)

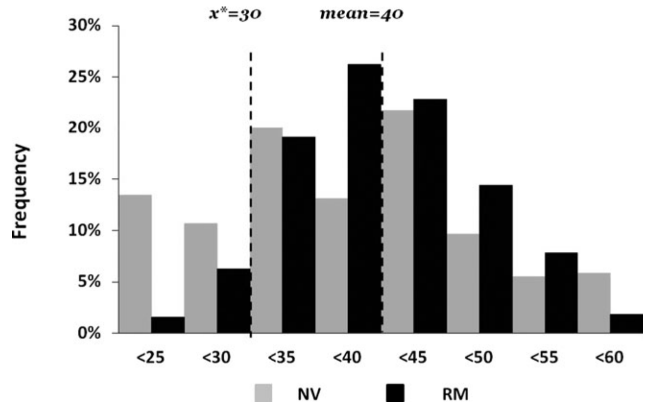
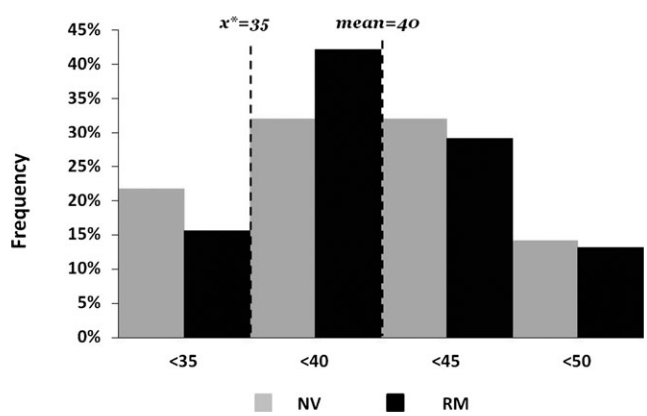



**Figure A8** Histogram of Subjects' Decisions: High-Cost Condition, *Uniform*(30,50)

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